AD NUMBER

AD828992

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

**Distribution authorized to U.S. Gov't. agencies and their contractors;
Administrative/Operational Use; 26 JAN 1968.
Other requests shall be referred to Air Force Technical Applications Center, Washington, DC 20330.**

AUTHORITY

AFTAC/USAF ltr 28 Feb 1972

DIGITAL COMPUTER PROGRAMS FOR THE DESIGN AND EVALUATION OF MULTICHANNEL FILTERS

26 January 1968

Prepared For

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C.

By

D. W. McCowan

TELEDYNE, INC.

Under

Project VELA UNIFORM

Sponsored By

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Test Detection Office
ARPA Order No. 624

DIGITAL COMPUTER PROGRAMS FOR THE DESIGN AND EVALUATION OF MULTICHANNEL FILTERS

SEISMIC DATA LABORATORY REPORT NO. 210

AFTAC Project No.:	VELA T/6702
Project Title:	Seismic Data Laboratory
ARPA Order No.:	624
ARPA Program Code No.:	5810
Name of Contractor:	TELEDYNE, INC.
Contract No.:	F 33657-67-C-1313
Date of Contract:	2 March 1967
Amount of Contract:	$ 1,736,617
Contract Expiration Date:	1 March 1968
Project Manager:	William C. Dean (703) 836-7644

P. O. Box 334, Alexandria, Virginia

AVAILABILITY

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Chief, AFTAC.

Washington, DC 20333

This research was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, under Project VELA-UNIFORM and accomplished under the technical direction of the Air Force Technical Applications Center under Contract F 33657-67-C-1313.

TABLE OF CONTENTS

INTRODUCTION

This report lists program write-ups for the multichannel filter program set written under the multichannel filter project here at the SDL. All of these programs were verified using these write-ups which are now as free from errors as possible. This set of programs should provide a reasonably complete capability to analyze signals and noise, design multichannel filters to enhance signals and suppress noise, evaluate the performance of these filters and prepare the punched paper tape which inputs the multichannel filters into the Texas Instruments Digital converter.

ALPHABETICAL LIST OF PROGRAMS

PROGRAM NAME	PURPOSE
1. G621 COLYTUKY	To compute spectra, correlations, and ordinary coherence functions using the Cooley-Tukey method.
2. G627 COHERNCY	To compute and plot ordinary coherences, phases, and auto spectra for a set of data channels.
3. G638 CONFIL	To convolve MCF impulse responses with a band-pass filter.
4. G624 FKSPTRUM	To contour-plot frequency-wavenumber spectra and array response functions.
5. G632 HEFALUMP	To design and apply the measured-noise isotropic processor.
6. G640 ISOFIL	To design and apply the theoretical isotropic processor.
7. G639 LSTCHNCE	To evaluate measured-noise and theoretical isotropic processor and maximum likelihood MCF performance.
8. Z124 MAXLIK	To design and apply the maximum-likelihood MCF.
9. M220 MCFONPT	To write paper tape images of MCF impulse response functions read from their respective save tapes onto magnetic tape.
10. M221 MCFONPT	To punch the magnetic paper tape image written by program M220 MCFONPT on paper tape using the 160 computer.
11. G630 MULTICOH	To compute and plot multiple coherence functions using the Cooley-Tukey method.
12. G631 PARTLCOH	To compute and plot partial coherence functions using the Cooley-Tukey method.
13. G636 PLOTFK	To contour-plot frequency-wavenumber spectra from an ensemble averaged spectral matrix read from tape.
14. G628 PREDICT	To design and apply time prediction and prediction-error filters.

15.	G635 SPECAVE	To compute an ensemble averaged spectral matrix from several samples of data.
16.	G625 TWX	To design and apply spatial interpolation and interpolation-error filters.
17.	G629 VFKSPTRUM	To contour-plot frequency-wavenumber spectra for a linear array.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: COLYTUKY

COOP Identification: G621 COLYTUKY

Category: Spectral Analysis

Programmer: J. Jih

Date: January, 1967

B. PURPOSE

This program computes auto-spectra, cross-spectra, auto-correlations, cross-correlations and coherencies using the Cooley-Tukey method. Fourier transforms of the data are first computed and then manipulated to give the desired results. This program is intended as an alternative to program BLACKY.

C. USAGE

1. Operational procedure: This is a Fortran-63 main program with the following subroutines: TAPER, SPLOT, SMOOTH, DETRND, and COOLER. In addition the following utility subroutines are assumed to be on the system tape: SKIPREC, ERASE, DISC63, and COOL.

2. Parameters:

   a) NJOB - the total number of separate job requests to be processed in this computer run. The program processes job requests in sequence, reading in the required data card each time.

   b) ITAPE - the logical tape number for the plot tape. This must not be 1, 5, or 6. If this is 0 or blank, no plots will be produced, and the following two parameters will not be used.

   c) NCODE - the spacing between plotted points in hundreths of an inch. NCODE = blank, 0, or 1 gives 100 points/in. NCODE= 2 gives 50 points/in. etc.

d) IRANGE - the number of hundredths of an inch corresponding to the maximum value of the plots. IRANGE = blank, or 500 gives ± 1 inch plots etc.

e) ISM - the seismogram number of the data.

f) ICH1 - the channel number for the first data channel, if one is all that is to be used. ie: ICH1 = 4, indicates the desired channel is the fourth on the input tape.

g) ICH2 - the channel number for the other data channel if required. ICH2 = 0 or blank, means no cross-spectrum, cross-correlation or coherency will be calculated.

h) ISPT - the first point of the requested data sample for each channel on the input tape.

i) NPTS - the number of data points in the sample. If ISPT and NPTS specify more points than exists on the input tape, the program cuts down NPTS. If NPTS is not a power of 2, it is truncated to the next power of 2 less than NPTS. NPTS $\leq$ 8192. NPTS $\leq$ 4096, if correlations are to be calculated.

j) ICROSP12-switch for the form of cross-spectra and cross-correlations. ICROSP12=0 or blank, gives ICH1 cross ICH2. ICROSP12 = 1 gives ICH2 cross ICH1.

k) ISMPT - the number of points desired after smoothing in the auto and cross spectra. This number is truncated to the next power of 2 plus 1 less than ISMPT if it is not so already, ie: 17, 33, 129 etc. If ISMPT = NPTS+1, 0 or blank, no smoothing will be done.

l) LAGS - the number of lags desired in the correlation function plots. LAGS/2 points are plotted on either side of the peak. Correlation functions are only plotted in this program, they are not printed. If LAGS = 0 or blank, no correlation functions will be computed.

m) DEMAG1 - demagnificati n factor for the first channel, (ICH1). This is divided into every point of ICH1. If DEMAG1 = 0.0 or blank, it is set to 1.0.

n) TPS - the fraction of the record to apply a cosine taper to the beginning. TPS = 0.0 or blank for no taper.

o) TPE - the fraction of the record to apply a cosine taper to the end. TPE = 0.0 or blank for no taper.

p) IDT - switch for detrending the data. IDT = -1 for no detrending. IDT = 0 to remove the mean. IDT = 1 to remove the mean and linear trend.

q) ILOG - switch for spectra plots. ILOG = 0 or blank gives linear plots. ILOG = 1 gives log to the base 10 plots.

r) IPLOT - switch for plots. IPLOT = 0 or blank means no plot is desired for this particular request. IPLOT = 1 means plot are desired for this request.

s) ICOH - switch for coherency. ICOH = 0 or blank means no coherency is desired for this request. ICOH = 1 means coherency is to be computed for this request.

t) IPH - switch for phase. IPH = 0 or blank means no phase is desired for this request. IPH = 1 means phase is to be computed for this request.

u) DEMAG2 - demagnification factor for the second channel, (ICH2).

3. Space required: 16510

4. Temporary space: Disc

5. Alarms: Three alarm messages are given for the following errors:
   a) The requested seismogram number is not on the input tape.
   b) A requested channel was not in the requested seismogram.
   c) A requested channel was the timing trace.

6. Error returns: none

7. Error stops: There are no stops. The program always proceeds with the next job request.

8. Tape mountings: An input tape of SUBSET seismograms must be on logical unit 1. If plots are desired, a plot tape must be on the unit specified by parameter (b).

9. Formats: The first card of the data deck lists parameters (a) through (d) as FORMAT (I8, 2I3, I5). It is followed by NJOB cards, one for each request, listing parameters (e) through (u) as FORMAT (I8, 2I3, 2I5, I2, 2I5, 3F5.2, 5I3, F5.2).

10. Selective jumps: none

11. Timing: Fast!

12. Accuracy: Single precision.

13. Caution to user: none

14. Equipment configuration: Standard COOP with E/5 = 50/6 = 51.

15. Reference:

D. W. McCowan, Finite Fourier Transform Theory and Its Application to the Computation of Convolution, Correlation and Spectra, UED Research Department Technical Memorandum Number 8-66, December 16, 1966.

D. METHOD

See reference.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: Coherency

COOP Identification: G627 COHERNCY

Category: Time Series Analysis

Programmer: V. Bruffey

Date: March, 1967

B. PURPOSE

To compute all the ordinary coherences, auto-spectra, and phases of a set of input data channels.

C. USAGE

1. Operational procedure:

This program is written in Fortran-63 and uses the following subroutines:

a) MAKESUB - this subroutine reads an input seismogram and produces another seismogram with the requested data.

b) XMNG - computes spectral-matrix.

c) SMOOTH - smooths spectra to requested length.

d) DETRND - removes mean and/or linear trend.

e) MATRA66 - computes matrix transpose.

f) COOLER - computes Fourier series expansion of a real-valued time series.

g) XPLOT - writes plot tape with scale factor as input.

2. Parameters:

a) ISEIS - the seismogram number of the data.

b) NCH - the number of channels to be processed.

c) NPTS - the number of data points in the sample. NPTS $\leq$ 4096. Also NPTS must be a power of 2.

d) ISPT - the first point of the requested data sample for each channel on the input tape.

e) IDT - switch for detrending the data. IDT = -1 for no detrending, IDT = 0 to remove mean, IDT = 1 to remove the mean and linear trend.

f) LF - number of points desired after smoothing. LF must be a power of 2 plus 1, and LF $\leq$ NPTS + 1. If LF = NPTS + 1, no smoothing is performed. LF is truncated to next power of 2 plus 1 if it is not already so.

g) IPRINT - switch for matrix print. If no matrix is desired, IPRINT $\neq$ 0. If IPRINT = 0, or left blank, the matrix printout is given.

h) ICH - an array of length NCH which specifies the data channel indicies. For example, if the input tape contains channels Z1, Z2, Z6, Z7, and Z9, respectively, and you want to process Z1, Z6, and Z9, then ICH(1) = 1, ICH(2) = 3 and ICH(3) = 5.

i) SF - an array of length NCH which specifies the demagnification factor for each channel. These are divided into every point of the data. If SF(I) = 0.0 or blank, it is set to 1.0.

j) ISPACE - the number of hundredths of an inch for each points along the frequency axis of the plot.

3. Storage required: 22644

4. Temporary storage: Disc

5. Error printouts:

If one of the following errors occur, the program will skip that set of input data, and proceed to the next set of inputs.

a) Seismograms not on tape.

b) Number of points not a power of two, or number of points is greater than 4096.

c) Data array larger than 20000. (i.e., NCH*NCH*LF > 20000).

d) Too many channels requested from seismogram.

e) Too many points requested from seismogram.

6. Tape mounting:

An input tape (subset tape) must be mounted on logical unit 3. Logical unit 2 is used along with 56 and 57 as a scratch tape, and logical unit 4 is used for the plot tape.

7. Input format:

Card 1: FORMAT(8I5)

Columns	Variables
1 - 5 (right adjusted integer)	ISEIS
6 - 10 (right adjusted integer)	NCH
11 - 15 (right adjusted integer)	NPTS
16 - 20 (right adjusted integer)	ISPT
21 - 25 (right adjusted integer)	IDT
26 - 30 (right adjusted integer)	LF
31 - 35	IPRINT
36 - 40	ISPACE

Card(s) 2: FORMAT(16I5)

Columns	Variables
1 - 5 (right adjusted integer)	ICH(1)
6 - 10 (right adjusted integer)	ICH(2)
.	.
.	.
.	.
76 - 80 (right adjusted integer)	ICH(16)

If the number of channels is greater than 16, then a second card must follow with columns (1-5) containing ICH(17), columns (6-10) containing ICH(18), etc.

Card(s) 3: FORMAT (8F10.5)

Columns	Variables
1 - 10	SF(1)
11 - 20	SF(2)
.	.
.	.
.	.
71 - 80	SF(8)

If number of channels is greater than 8, then a second (and maybe 3rd or 4th) card is used with (1-10) containing SF(9), 11-20 containing SF(10) etc.

Note: The program works for multiple input sets, but assumes all seismograms being processed on one run, are on the same subset tape. Also, a single seismogram may be processed over and over on the same computer run.

8. Selective jumps: none

9. Timing: 10 channels of 4096 points each and smoothing to 129 points requires about 20 minutes.

10. Accuracy: single precision

11. Caution to user: NCH*NCH*LF $\leq$ 20000
LF$\leq$NPTS$\leq$ 4096, LF $=2^x + 1$, NPTS $= 2^y$ for some x and y.

12. Output: The output is:

(1) LF square matrices of dimension NCH*NCH. The upper half of the matrices contains coherences, the lower half contains the phases scaled by π and the diagonal contains the auto-spectra scaled by their largest value, so that they lie between 0 and 1. The print out is omitted if IPRINT $\neq$ 0. If NCH > 16, a two page print is used.

(2) NCH plots, where each plot has LF*NCH points and each plot can be broken down into NCH segments. For example, if NCH = 3 then plot #1 would contain

the auto-spectra of channel 1, the coherency between channels 1 and 2, and the coherency between channels 1 and 3. The second plot would contain the phase between channels 2 and 1, the auto-spectra of channel 2, and the coherency between 2 and 3. Finally, the third plot would contain the phase between channel 3 and 1, the phase between channels 3 and 2, and the auto-spectra of channel 3. The resulting plot matrix is shown below.

Plot 1	Auto-spectra(1,1)	Coherency (1,2)	Coherency (1,3)
Plot 2	Phase (2,1)	Auto-spectra (2,2)	Coherency (2,3)
Plot 3	Phase (3, 1)	Phase (3,2)	Auto-spectra (3,3)

Thus, the upper half of the plot matrix contains the coherences the lower half contains the phases, and the diagonal contains the auto-spectra.

13. Equipment configuration: standard COOP.

D. METHOD

The computational method is given by the following step procedure.

1) Select subsetted data.

2) Compute the spectral matrix of the selected data. This is performed by subroutine XMNG. The results are stored in matrix form with imaginary components above the diagonal, real components below the diagonal, and the auto-spectra on the diagonal.

3) Compute coherences using

$$C_{ij}(w) = \sqrt{\frac{S_{ij}(w)}{S_{ii}(w)\ S_{jj}(w)}},\ i \neq j$$

Since $C_{ij}(w) = C_{ji}(w)$ and $C_{ii}(w) = 1$, the upper half of the matrix is used for storing the phase relations defined by:

$$\text{phase } ij(w) = \frac{1}{\pi} \text{TAN}^{-1} \left(\frac{\text{Imaginary } S_{ij}(w)}{\text{Real } S_{ij}(w)} \right),\ i \neq j$$

The auto-spectra are scaled by their largest value and left on the diagonal.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computing Section

A. IDENTIFICATION

Title: Band-Pass Filter Convolution Program

COOP Identification: G638 CONFIL

Category: Time Series Analysis

Programmer: D. W. McCowan

Date: November, 1967

B. PURPOSE

This program reads band-pass filter coefficients from cards and convolves them with the impulse response of a multichannel filter read from tape. It is designed to process two kinds of multichannel filters, the measured-noise and isotropic processors, from their save tapes. Any band-pass filter may be used provided the number of coefficients in its impulse response does not exceed 100.

C. USAGE

1. Operational Procedure: This is a Fortran-63 main program.

2. Parameters:

a) JWORD - a word indicating the type of save tape to process

JWORD=6HISOFIL for theoretical MCF

JWORD=8HHEFALUMP for measured-noise MCF.

b) NFP - the number of coefficients in the band-pass filter impulse response. NFP$\leq$100

c) FIL (I) - the Ith band-pass filter coefficient

3. Space required: 32 K

4. Temporary storage: None

5. Alarms: Various alarms for illegal data are printed out

6. Error returns: None

7. Error stops: A stop occurs after each alarm

8. Tape mountings: Tape unit 1 is the input save tape on which is stored the MCF filter, Tape unit 2 is the output tape in the same format as the input save tape but with the MCF now convolved with the B-P filter.

9. Input and output formats: Parameter (a) appears on the first card, as FORMAT (A8). Parameter (b) appears on the next card as FORMAT (I10). Parameters (c) appear on the following cards as FORMAT (5x,E15.7).

10. Selective jumps: None

11. Timing: Fast

12. Accuracy: Single precision

13. Cautions to user: None

14. Equipment configuration: Standard COOP with RELOCOM, and two (2) tape units.

15. References: None

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: FKSPTRUM

COOP Identification: G624 FKSPTRUM

Category: Time Series Analysis

Programmer: J. Jih

Date: January 1967

B. PURPOSE

To compute and display the frequency-wave number power spectra of seismic noise along with a response function for the corresponding array. This program is intended as a replacement for certain parts of program, PEAKAY using the Cooley-Tukey method to estimate auto and cross power spectral density functions.

C. USAGE

1. Operational procedure: This is a Fortran-63 main program with the following subroutines: COOLER, SMOOTH, DETRND, LOCATION, FKMAT, and CNTUR5. In addition the following utility subroutines are assumed to be on the system tape: SKIPREC, ERASE, DISC63, and COOL.

2. Parameters:

a) NJOB - the total number of separate job requests to be processed in this computer run. The program processes job requests in sequence, reading in the required data cards each time.

b) ISM - the desired seismogram number for this job.

c) N - the desired number of input data channels ($\leq$ 27).

d) NF - the number of frequencies for which f-k spectra are to be computed ($\leq$ 24).

e) ISPT - the first point of the requested data sample for each channel on the input tape.

f) LX - the number of data points in the sample. If ISPT and LX specify more data points than exist on the input tape, the program goes on to the next job request. LX is always truncated to the next power of 2 less than LX if it is not so already. In the following discussion this value will be referred to as LXT. LXT $\leq$ 4096.

g) ISMPT - the number of points desired after smoothing in the auto and cross power spectral density functions. This number is truncated to the next power of 2 plus 1 less than ISMPT if it is not so already, i.e., 17, 33, 129, etc. In the following discussion this value will be referred to as ISMPTR. If ISMPT = 0 or blank, no smoothing will be done on the spectra and ISMPTR will be set to LXT+1. ISMPTR$\leq$LXT+1$\leq$4097.

h) IRESP - switch for requesting an array response.
IRESP>0 gives a response plot with the FK spectra.
IRESP=0 gives no response plot with the FK spectra.
IRESP<0 gives a response plot only and no FK spectra.

i) NKX and NKY - the number of KX and KY values respectively for which the f-k spectra and the array response function are to be computed. (NXK $\leq$ 63, NKY $\leq$ 63). These numbers must also be odd.

j) ICH (I) - the position of the Ith data channel on the input tape. ie: ICH(I) = 4 indicates the Ith channel is the fourth on the input tape. (I $\leq$ N).

k) XAXIS (I),& YAXIS (I) - the X and Y coordiantes the Ith channel. The computed spectra and response function will be for arguments of one over these units. (I $\leq$ N).

l) SF(I) - a demagnification or scale factor for the Ith channel, which is divided into the data. (I $\leq$ N_.

m) FREQ (I) - the Ith requested frequency. These numbers must be in increasing numeric order.

n) VELR - the velocity range for all spectra plots.

o) FKX and FKY - the lowest values of KX and KY for the response plot if requested.

p) DKX and DKY - the increment of KX and KY for the response plot if requested.

3. Space required: 20807

4. Temporary space: Disc

5. Alarms: Four alarm messages are given for the following errors:

   a) The requested seismogram number is not on the input tape.

   b) The requested data exceeds the data on the input tape.

   c) The number of channels exceeds the number of channels on the input tape.

   d) A requested channel was the timing trace.

6. Error returns: none

7. Error stops: There are no stops. The program always proceeds with the next job request.

8. Tape mountings: An input tape of SUBSET seismograms must be on logical unit 1.

9. Formats: The first card of the data deck lists parameter (a) as FORMAT (I8). It is followed by NJOB request decks. The first card of each request deck lists parameters (b) through (i) as FORMAT (I8, 2I4, I2, 3I6, 2I5). The next cards list parameters (j), (k), and (l) as FORMAT (3(I3), F8.2, F6.2)). The next cards list parameter (m) as FORMAT (12F6.2). The last card in each request deck lists parameters (n) through (p) as FORMAT (5F6.2). There must be no blank cards. The next request deck follows, if IRESP<0 parameters (b),(d),(d),(f),(g),(l),(m), and (n) are not needed. Furthermore the card listing parameter (m) is not read.

10. Selective jumps: none

11. Timing: A NKX = NKY = 21, N = 10, LX = 4096, ISMPT = 257, IRESP = 1, NF = 6 case takes 24 minutes of CDC 1604B time.

12. Accuracy: Single precision

13. Caution to user: All data is detrended

14. Equipment configuration: Standard COOP with E/5 = 50/6 = 51. A RELCOM card is required.

15. References:

D. W. McCowan, Finite Fourier Transform Theory and Its Application to The Computation of Convolutions, Correlations, and Spectra, UED Research Department, Technical Memorandum Number 8-66, December 16, 1966.

D. METHOD

The frequency-wave number power spectra are computed from the spectral matrix elements by the following relation:

$$P(f,k_x,k_y) = \sum_{i=1}^{N} \sum_{j=1}^{N} S_{ij}(f) \exp 2\pi i(k_x(x_i-x_j) + k_y(y_i-y_j))$$

The spectral matrix elements are computed as described in the reference.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: Measured Noise Isotropic Processor

COOP Identification: G632 HEFALUMP

Category: Time Series Analysis

Programmer: D. W. McCowan

Date: September, 1967

B. PURPOSE

This program computes and/or applies a multichannel isotropic processor to seismic array data. An actual noise model is used computed from the spectra of a specified data sample. Either a point or a disc signal model can be computed. The program then solves the multichannel Wiener-Hopf equation in the frequency domain to get the optimum filter which rejects the noise and passes the signal. The filter is written on a save tape for future use. An option exists to filter a given piece of data and plot the filtered trace and the direct sum. PERSON plots are also generated and plotted which, in conjunction with the output plots, allow the user to calculate signal to noise ratios.

C. USAGE

1. Operational procedure: This is a Fortran-63 main program with the following subroutines: COMFIL, RESCALAT, COOLER, DETRND, MATMPY63, MATRA63, SMOOTH, SMNG, TRANSIT, FOOBACK, MAKESUB, BES, COOLCON, PLOTEM, PERSON66, and SPLOT. In addition, the following utility subroutines are assumed to be on the system tape: ERASE, COOL, and DISC63.

2. Parameters:

a) ISEIS - The seismogram number of the noise sample.

b) NCH - The number of channels in the filter. NCH $\leq$ 13.

c) NPTS - The number of points from seismogram ISEIS to use. This must be a power of two. NPTS $\leq$ 4096.

d) ISPT - The first point of the noise sample.

e) IDT - The detrend switch for the noise sample.
IDT = -1 for no detrending
IDT = 0 to remove the mean only
IDT = 1 to remove the mean and linear trend.

f) L - The number of points in the frequency representation of the filters. This must be a power of two plus one; i.e., 17, 33, 129 etc. L $\leq$ 129. The number of points in the time representation of the filters, the impulse response will be 2*(L-1)-1.

g) ISW - A control switch
=1 to compute the spectral matrix, compute the filter and filter the data.
=2 to read the spectral matrix from the save tape, compute the filter and filter the data.
=3 to read the spectral matrix and the filter from the save tape and filter the data.

h) IND - The data channel to use as a signal power spectrum.

i) SNR - The desired signal to noise ratio. We have found SNR = 4.0 to work well.

j) VEL - The signal velocity for a disc model if one is used. The filters will pass "signals" with any velocity greater than VSG.

k) IPER - The percentage of white noise to add to the signal model. The white noise stabilizes the computation and assures good convergence in the filters. We have found that two or three percent is usually adequate.

l) IDISCSIG - A control switch for the signal model.
= 0 for an infinite velocity signal model.
= 1 for a disc signal model V $\geq$ VSG.

m) ICH(I) - An array giving the positions of the NCH data channels used as a noise sample on the input tape. ICH(I) = 4 indicates the Ith channel is the fourth on the input tape. The entries in ICH must be in increasing numeric order.

n) X(I) - The X coordinate of the Ith data channel.

o) Y(I) - The Y coordinate of the Ith data channel.

p) SF(I) - A scale or demagnification factor for the Ith data channel. If SF(I) = 0.0 or blank it is set to 1.0.

q) ISEIS1 - The seismogram number of the data to be filtered.

r) NPTS1 - The number of points to be filtered. NPTS1 $\leq$ 3500.

s) ISPT1 - The first point to be filtered.

t) IDT1 - The detrend switch of the data to be filtered.

u) ICH1(I) - The position of the Ith data channel to be filtered.

v) SF1(I) - The demagnification factor for the Ith data channel to be filtered.

3. Space required: 32K locations

4. Temporary storage: Disc

5. Alarms: Various alarms for illegal data are printed out.

6. Error returns: none

7. Error stops: A stop occurs after each alarm.

8. Tape mountings: Tape unit 1 is the input subset tape with both the noise sample and the data to be filtered. Tape 2 is the plot tape. Tape unit 3 is the save tape which should be a scratch tape if ISW = 1 or 2 and an input tape when ISW = 3. Tapes 4 and 5 are scratch tapes.

9. Input and output formats: Input cards:

Parameters (a) through (l) appear on the first card as FORMAT (I10, 7I5, E15.3, F10.2, 2I3). Parameters (m) through (p) appear on the next cards as FORMAT (3(I3, 2F8.2, F6.2)). Parameters (q) through (t) appear on the next card as FORMAT (4I10). Parameters (u) and (v) appear on the last cards as FORMAT (3(I3, 10X, F6.2)).

Save tape:

The save tape consists of one file of binary data written in three logical records. The first record is a 127 word label written as follows:

LAB(1) = ISEIS
LAB(2) = NCH
LAB(3) = NPTS
LAB(100) = IDT
LAB(101) = L
LAB(102) = ISW
LAB(103) = IND
LAB(104) = SNR
LAB(105) = VEL
LAB(106) = IPER
LAB(107) = IDISCSIG
LAB(58--58+NCH-1) = X
LAB(79--79+NCH-1) = Y

The second record is a 21801 word array with the spectral matrix stored close packed as follows:

$S_{ij}(w)$ = S(i,j,w), ((S(i,j,w), i=1,NCH), j=1,NCH),w=1,L)

The third record is a 5397 word array with the filter stored close packed as follows:

$F_i(t)$ = F(i,t), ((F(i,t), i=1,NCH), t=1,2*(L-1)-1)

10. Selective jumps: none

11. Timing: A 13 channel 129 point filter computed and applied to 3500 points of data required about 45 minutes of CDC 1604B time.

12. Accuracy: Single precision.

13. Cautions to user: It is not possible to generate a plot of the correlation matrix with this program.

14. Equipment configuration: Standard COOP with RELOCOM

15. References: Seismometer Array and Data Processing System, Project Vela-Uniform-AFTAC,Project VT/007, Final Report, Phase 1, ARPA Order No. 104-60.

D. METHOD

See reference

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: Theoretical Isotropic Processor

COOP Identification: G640 ISOFIL

Category: Time Series Analysis

Programmer: D. McCowan

Date: August, 1967

B. PURPOSE

This program computes and/or applies a multichannel isotropic processor to seismic array data. An annular ring noise model and either a point or a disc signal model can be specified. The program then solves the multichannel Wiener-Hopf equation in the frequency domain to get the optimum filter which rejects the noise and passes the signal. The filter is written on a save tape for future use. An option exists to filter a given piece of data and plot the filtered trace and the direct sum. PERSON plots are also generated and plotted which, in conjunction with the output plots, allow the user to calculate signal to noise ratios.

C. USAGE

1. Operational procedure: This is a FORTRAN-63 Main program with the following subroutines: DISMAT, NMAT, SMAT1, SMAT2, RMAT1, RMAT2, APDEM, INVERT, MATMPY, GETEM, COOLCON, PLOTEM, BES, SPLOT, DETRND, and PERSON66. In addition, the following utility subroutines are assumed to be on the system tape: ERASE, and COOL.

2. Parameters:

a) NCH - The number of channels in the filter, NCH$\leq$21.

b) SR - The desired sampling rate, usually the same as the data.

c) SNR - The desired signal to noise ratio. We have found SNR=4.0 to work well.

d) VSG - The signal velocity for a disc model if one is used. The filters will pass "signals" with any velocity greater than VSG.

e) VNL - The lower velocity limit of the noise band.

f) VNH - The upper velocity limit of the noise band. The filters will reject "noise" between these two velocities.

g) IMODE - A control switch.
= 1 to compute the filter and filter the data
= 0 to read the filters from the save tape and filter the data.

h) L - The number of points in the frequency representation of the filters. This must be a power of two plus one; ie., 17, 33, 129 etc. $L \leq 129$. The number of points in the time representation of the filter, the impulse response, will be 2*(L-1)-1.

i) IPER - The percentage of white noise to add to the signal model. The white noise stabilizes the computation and assures good convergence in the filters. We have found that two or three percent is usually adequate.

j) IDISCSIG - A control switch for the signal model.
= 0 for an infinite velocity signal model.
= 1 for a disc signal model $V \geq VSG$.

k) ISEIS - The seismogram number of the data to be filtered.

l) NPTS - The number of points to be filtered. $NPTS \leq 3500$.

m) ISPT - The first point of seismogram ISEIS to be filtered.

n) IDT - The detrend switch for the data to be filtered.
= - 1 for no detrending.
= 0 to remove the mean.
= 1 to remove the mean and linear trend

o) ICH(I) - An array giving the positions of the NCH data channels to be filtered on the input tape. ICH(I) = 4 indicates the I^{th} channel is the fourth on the input tape. The entries in ICH must be in increasing numeric order.

p) X(I) - The X coordinate of the I^{th} data channel.

q) Y(I) - The Y coordinate of the I^{th} data channel.

r) SF(I) - A scale or demagnification factor for the Ith data channel. If SF(I) = 0.0 or blank it is set to 1.0.

3. Space required: 26K locations.

4. Temporary storage: none

5. Alarms: Various alarms for illegal data are printed out.

6. Error returns: none

7. Error stops: A stop occurs after each alarm.

8. Tape mountings: Tape unit 1 is the save tape which should be a scratch tape when the filters are being computed and an input tape when they are being read. Tape unit 3 is the input subset tape with the data to be filtered. Tape 5 is the plot tape and tapes 2 and 4 are scratch tapes.

9. Input and output formats: Input cards.

Parameters (a) through (j) appear on the first card as FORMAT (I5, F10.2, E15.3, 3F10.2, 4I5). Parameters (k) through (n) appear on the next card as FORMAT (I10, 6I5). Parameters (o) through (r) appear on the last cards as FORMAT (3(I3, 2F8.2, F6.2)).

Save tape:

The save tape consists of one file of binary data written in two logical records. The first record is a 127 word label written as follows:

LAB(1) = NCH
LAB(2) = SR
LAB(3) = SNR
LAB(4) = VSG
LAB(5) = VNL
LAB(6) = VNH
LAB(7) = L
LAB(8) = IPER
LAB(9) = IDISCSIG
LAB(10--10+NCH-1) = X
LAB(31--31+NCH-1) = Y

The second record is a 5376 word array with the filters stored close-packed as follows:

$F_i(t) = F(I,t)$, ((F(I,t), I=1, NCH), t=1,2*(L-1)-1)

10. Selective jumps: none

11. Timing: A 13 channel 129 point filter computed and applied to 3500 points of data requires about 24 minutes of CDC 1604B time.

12. Accuracy: Single precision

13. Cautions to user: Do not exceed ranges of NCH and L as no error message is given for these signs.

14. Equipment configuration: Standard COOP with RELOCOM.

15. References: Seismometer Array and Data Processing System, Project Veal-Uniform-AFTAC, Project VT/007, Final Report, Phase 1, ARPA Order No. 104-60.

D. METHOD

See reference.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: Multichannel Filter Evaluation Program

COOP Identification: G639 LSTCHNCE

Category: Time Series Analysis

Programmer: D. W. McCowan

Date: November, 1967

B. PURPOSE

This program computes and displays the f-k, white noise, and amplitude response functions for theoretical and measured-noise and also maximum likelihood filters. The program plots contours of the f-k transfer function, and plots the white noise and amplitude transfer functions.

C. USAGE

1. Operational Procedure: This is a Fortran-63 main program assuming the following subroutines on the system tape: ERASE, DISC63, ABMAX, SKIPREC, and COOL.

2. Parameters:

a) JWORD - a word indicating the type of save tape to process.
JWORD = 6HMAXLIK for maximum-likelihood filter
JWORD = 6HISOFIL for theoretical MCF
JWORD = 8HHEFALUMP for measured-noise MCF

b) ISMPT - the number of points in frequency to which to smooth the MCF response functions. This must be a power of two plus one. ISMPT$\leq$65.

c) NF - the number of frequencies for which f-k contour plots of the f-k transfer function are desired NF$\leq$12.

d) VELR - the velocity range for all f-k plots.

e) ILOG - a switch for linear/log plots of the white noise and amplitude transfer functions.
ILOG = 0 generate linear plots
ILOG ≠ 0 generate db plots

f) NCODE - the spacing between plotted points in hundredths of an inch

g) RANGE - the range in inches for all plots

h) X (I) - the X coordinate of the Ith seismometer.

i) Y (I) - the Y coordinate of the Ith seismometer.

j) FREQ (I) - the Ith requested frequency

3. Space required: 32 K

4. Temporary storage: disc

5. Alarms: various alarms for illegal data are printed out.

6. Error returns: none

7. Error stops: a stop occurs after each alarm

8. Tape mountings: Tape unit 1 is a scratch tape. Tape unit 2 is the input save tape being processed. Tape unit 3 is the output plot tape.

9. Input and output formats: Parameter (a) appears on the first card as FORMAT (A8). Parameters (b) through (g) appear on the next card as FORMAT (2(2I5, F10.2)). Parameters (h) and (i) appear on the next cards as FORMAT (3(3X, 2F8.2, 6X)). Parameter (j) appears on the last card as FORMAT (12F6.2).

10. Selective jumps: none

11. Timing: same as FKSPTRUM for time series the length of the filters.

12. Accuracy: single precision

13. Cautions to user: none

14. Equipment configuration: standard COOP with RELOCOM, three (3) tape units and 818 disc file.

15. References: D. W. McCowan, Multichannel Filter Report, In preparation.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: Maximum Likelihood Filter Program

COOP Identification: UES Z124 MAXLIK

Category: UES General

Programmer: D. W. McCowan

Date: June, 1967

B. PURPOSE

This FORTRAN-63 program computes and/or applies a 21 or 30 point maximum-likelihood filter (realizable or symmetric) to seismic array data. Printed output is produced as well as a plot tape displaying the input and output data and useful computed information. In addition, a save tape is generated with all pertinent data about the operation written in an easily accessible form. A provision exists to run the program from the save tape processing new data with both kinds of maximum-likelihood filters. In this case, either filter is efficiently re-computed from information written on the save tape and a new save tpae is generated with details of the new filter and its operation.

The printed output includes the actual summation constraint satisfied by the filter coefficients. This is, for realizable filters,

$$\sum_{i=1}^{L} f_i(t) = \delta_1^t$$

and for symmetric filters,

$$\sum_{i=1}^{L} f_i(t) = \delta_{L/2}^t$$

The user can see from this how accurate the Levinson recursion was in calculating the filters. Also included are partial energy sums for both output traces, the maximum-likelihood and the direct sum.

They are:

$$P(t) = \sum_{t=1}^{t} x(t)^2 ,$$

and are referred to in the output as PERSON values. These are useful for computing RMS noise measurements over some arbitrary interval. The two maximum absolute values, one for the input traces and the other for the two outputs, are also printed.

The plot tape contains plots of the input traces, all to the same scale factor and the two output traces also to their own common scale factor. The PERSON values are plotted to separate scale factors.

The user is referred to the various papers, both published and unpublished, on the theory of maximum-likelihood filters for a thorough technical discussion. These references also provide definitions for the quantities described in this write-up. This particular write-up will not concern itself with the theory of maximum-likelihood filters, the general practices of maximum-likelihood filtering, or the operation of the sub-routines in this program set. For the rest of these subjects the user is also referred to the papers and reports listed as well as the write-ups of the mathematical subroutines we have written for this program.

C. USAGE

1. Operational procedure: This is a FORTRAN-63 main program using the overlay option provided with the 1604-B COOP monitor. It is usually run from the relocatable binary deck under standard monitor control; although it can be run from the overlay tape using the LOADMAIN system.

In general two kinds of runs can be made with this program. The first is a "Compute" run and entails the computation of the maximum-likelihood filters from the ground up. The other kind of run is a "Filter-Only" run in which the filter is read from the save tape and applied to new data. Because of this, the Parameters section is divided into two parts, the first describing the parameters necessary for a "Compute" run and the second part describing those required for a "Filter-Only" run.

2.1 Parameters - compute run:

a) IWORD - filter length switch,

IWORD = 8HMAXLIK21, for a 21 point filter

IWORD = 8HMAXLIK30, for a 30 point filter.

b) ISEIS - the seismogram number of the data from which the filter is to be computed.

c) NCH - the number of channels to be used in computing the filter, (NCH≤21 for a 21 point filter, NCH≤10 for a 30 point filter.

d) NPTS - the number of points in the fitting interval, (NPTS≤6000)

e) ISPT - the first point of the fitting interval on seismogram ISEIS.

f) IDT - the trend switch for the fitting interval data,

IDT = -1, no detrending
IDT = 0, mean removed
IDT = 1, mean and linear trend removed.

g) JUMP - the number of digital points per unit correlation. This determines the sampling rate of the correlation functions, and thereby the filters, in terms of the sampling rate of the input data.

JUMP = 1, the sampling rate of the filters is the same as that of the data.
JUMP = 2, the filters are to be sampled every other data points.
JUMP = 3, the filters are to be sampled every third data point.

etc.

h) ISOR - the filter designation switch,

ISOR = 1, compute symmetrical filter
ISOR = 0, compute realizable filter

i) IFOC - the run designation switch.

IFOC = 1, "Filter-Only" run
IFOC = 0, "Compute" run.

j) ICH - Array of positions of the NCH data channels to be re-subset from the input SUBSET tape; i.e., NCH = 3, ICH = (2,4,5) indicates that the second, fourth, and fifth channels on the input tape are to be used. The channels must be listed in increasing order.

k) SF - Array of demagnification on scale factors for the NCH selected data channels.

l) ISEIS1 - the seismogram number for the data to be filtered.

m) NCH1 - the number of channels to be filtered. NCH1 must equal NCH.

n) NPTS1 - the number of points of seismogram ISEIS1 to be filtered (NPTS1≤6000).

o) ISPT1 - the first point of seismogram ISEIS1 to be filtered.

p) IDT1 - the detrend switch for the data to be filtered.

q) ICH1 - array of channel positions of the input tape for the data to be filtered.

r) SF1 - array of demagnification factors.

2.2 Parameters - Filter-only run:

a) IWORD - the filter length designation switch

b) ISOR - the filter designation switch

c) IFOC - the run designation switch.

d) ISEIS1 - as above

e) NCH1 - as above

f) NPTS1 - as above

g) ISPT1 - as above

h) IDT1 - as above

i) ICH1 - as above

j) SF1 - as above

3. Space required: 32 K

4. Temporary space: none

5. Alarms: Various alarms caused by illegal data requests are flagged by subroutine MAKESUB. The user is referred to the write-up of subroutine MAKESUB for their meanings. In addition, as subroutine MAKESUB does not stop, the main program also indicates an error has taken place. It is flagged, though not designated, and the job is terminated.

6. Error returns: none

7. Stops: The program halts if an error condition in subroutine MAKESUB is detected.

8. Tape mountings: The input subset tape for either kind of run must be mounted on logical tape 1. The plot tape is logical tape 4 and the save tape is logical tape 3. In a "filter only" run, another save tape must be input on logical tape 5. Logical tape 5 is used only for scratch in a "compute" run. Logical tape 6 is the overlay tape and must be low density (the cover card must contain this instruction). Logical tape 2 is a scratch and can be equivalenced to 56, as it is initially rewound.

9.1 Card formats - compute run: Parameter (a) appears on the first card as FORMAT (A8). Parameters (b) through (i) appear on the second card as FORMAT (8I10). Parameter (j) appears on the next card as FORMAT (2I13). Parameter (k) appears on the next card as FORMAT (4E20.3). Parameters (l) through (p) appear on the next card as FORMAT (5I10). If parameter (l) is zero or blank, no further cards are read and the data to be filtered will be the same as the data used to compute the filter. Otherwise, parameter (q) appears on the next card as FORMAT (25I3) and parameter (m) appears on the last cards as FORMAT (4E20.3).

9.2 Card formats - filter-only run: Parameter (a) appears on the first card as FORMAT (A8). Parameters (b) and (c) appear on the second card as FORMAT (60X, 2I10). Parameters (d) through (h) appears on the next card as FORMAT (25I3) and parameter (i) appears on the next card as FORMAT (5I10). Parameter (j) appears on the last cards as FORMAT (4E20.3).

9.3 Save tape format: The save tape consists of 8 files of binary data as described below:

File	Record	Length	Quantity	Description
1	1	225	label	LAB (1) = ISEIS LAB (2) = NCH

File	Record	Length	Quantity	Description
				LAB (3) = NPTS LAB (4) = ISPT LAB (5) = IDT LAB (6) = JUMP LAB (7) = ISOR LAB (8) = IFOC (LAB (39+I),I=1, NCH)=ICH (LAB (39+I),I=1, NCH)=SF LAB (100) = L
EOF				
2	1	9261	R	See Reference
EOF				
3	1	255	label	Same as above but for data to be filtered.
EOF				
4	1	9261	$E=R^{-1}G(G^{T}R^{-1}G)^{-1}$	See reference 3.
EOF				
5	1	441	F=ED	See reference 3.
EOF				
6	1	127 or 256	label	Input tape label as set for data to be filtered. data channels
	2-NCH+1	LAB (3)	data	
EOF				
7	1	1	LX	Length of phased sum
	2	LX	Phased sum	
EOF				
8	1	1	LX	Length of max-like trace
	2	LX	max-like	
EOF				

10. Selective jumps: none

11. Timing: The times required to calculate the correlation matrix and the filter are given by:

$$T_c = 1.83 \times 10^{-6}.N^2.L.LX$$

$$T_f = 1.65 \times 10^{-5}.N^3.L^2$$

respectively. T is in minutes of 1604-B time, N is the number of channels, L is the filter length, and LX is the number of points in the fitting interval. The time to do the convolutions and generate the plot varies; however, 19 channels of 4800 points each requires about 12 minutes of 1604-B time.

12. Accuracy: Single precision.

13. Caution to users: Text above

14. Equipment configuration: Standard COOP. Typical COOP cards for a "Compute" run and a "Finite-only" run are given below:

a "Compute" run and a "Filter-Only" run are given below:

```
7 COOP, 23499, BULOVA, I/1/S/3/4/5/6/56/57/E/2 = 56, 140,
9 500.
```

```
7 COOP, 23499, BULOVA, I/1/5/S/3/4/5/6/56/57/E/2 = 56,
9 140, 500.
```

15. References:

(1) Bruffey, V., Write-up of Z122 MAKESUB, Seismic Data Laboratory, March, 1967.

(2) Fletcher, N.H. Write-Up of Z24 SUBSET, Seismic Data Laboratory, September, 1964.

(3) Flinn, E. A., and Claerbout, J.F., Some Topics in Digital Filtering, Theory and Application, Seismic Data Laboratory, Internal Memorandum, September 16, 1965.

(4) Flinn, E. A., et.al., Two Examples of Maximum Likelihood Filtering of LASA Seismograms, Seismic Data Laboratory, Report No. 148, June, 1966.

(5) Flinn, E.A., et.al., Maximum Likelihood Filtering of LASA Noise Seismograms, Seismic Data Laboratory, Report No. 149, June 8, 1966.

(6) McCowan, D. W., Write-Up of E509 PHILTRE, Seismic Data Laboratory, NOvember, 1965.

(7) McCowan, D. W., Write-Up of Z78 MCORT, Seismic Data Laboratory, September, 1965.

(8) McCowan, D.W., Write-Up of E509 MAX-LIKE, Seismic Data Laboratory,March, 1965.

D. METHOD

See references.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: Multi-channel Filter to Paper-Tape Format

COOP Identification: M220 MCFONPT

Category: Conversion

Programmer: C. W. Clowes

Date: 2 October 1967

B. PURPOSE

Reads either on ISOFIL, MAXLIK or HEFALUMP save tape. Scales and converts selected channels to punch paper tape format and places on a MCFONPT save tape. The MCFONPT save tape is punched by 160A program PUNCH MCFONPT.

C. USAGE

1. Operational Procedures: Operator must be supplied with 3 data cards describing tape to read, channels on tape and number of filters to punch.

2. Parameters:

a) Card Format (I3, 6X, A8, 2X, 2I3/(BI3))

b) Card 1
cc 1-3 NF - Number of filter channels to be punched.
10-17 ISW - Name of input tape. (left justified)
MAXLIK, ISOFIL or HEFALUMP
20-22 SC - Scaling constant (usually 63)
23-25 IOIND - Output channel index.

c) cc 1-39 Array ICH(I), I=1,13
Array for channel identifiers on input tape. Range 0-12. Punch starting column 1, 3 columns per channel number, is ascending order. Example: ICH(7)=4, Indicates 2nd filter on magnetic tape corresponds to the 4th array channel, i.e. Z4.

d) cc 1-39 Array JCH(I), I=1,B.
Array identifying channels that are to be punched.

Range 0-12. Punch on card starting column 1, 3 columns per channel number, in ascending order. Caution: Channels listed in this array must be listed in ICH array.

3. Space Required: Program requires 14600 locations

4. Temporary Storage:

5. Print-Outs:

   a) Channel No. selected is not on input tape or data card is wrong.

   b) Printout also lists:
      i. input tape name
      ii. number of filters on tape
      iii. number of filters to be processed
      iv. channel numbers on tape (ICH)
      v. channel numbers to process (JCH)

   c) A compiled list of all of the filters processed is printed.

6. Error Return: If an error in the number of filter channels selected occurs, control is returned to the monitor.

7. Error Stops: None

8. Input and Output Tape Mountings: Input: Lo Unit 1
   Output: Lo Unit 2

9. Input and Output Formats:

   a) Card input (see parameters)
   b) Tape input (1) is output from MAXLIK (Unit 3), ISOFIL (Unit 1) HEFALUMP (Unit 3).
   c) Tape output (2). 13 records of 13 channels. Each record consists of one channel x number of filter coefficients.

10. Selective jump and stop settings: Switch 1 on to bypass printout of filter coefficients.

11. Timing: Processing maximum of 13 channels of 255 filters coefficients with printout takes 6 minutes. SW 1 on takes considerably less.

12. Accuracy: Filters are scaled and truncated to a four digit octal integer, range -3777 to +3777.

13. Caution to User: Channel filters range from 0 through 12 on data cards and printouts. Filters listed on card 3 must be present on tape and card 2.

14. Equipment Configuration: Standard COOP. 1604 processor, 2 tape drivers, 1607 printer, card reader.

15. References: Write-up of HEFALUMP, ISOFIL, MAXLIK by D. W. McCowan. Texas Instruments, 1966, Operation and Maintanence of The CPO Multichannel Filter System. Instruction Manual.

D. METHOD

The data is read from either tapes ISOFIL, MAXLIK or HEFALUMP into array FILCOEF. Channels to be processed (JCH) are compared to channels on tape (ICH) and the channels listed in JCH are scaled. All scaled filters are then compared using the following scheme:

$$NF \cdot LF \cdot SC \cdot FMAX = A$$

where NF is number of filter channels to punch.
LF is number of filter points/channel.
SC is scale constant (from data card)
FMAX is max. absolute filter point.

if $A \geq 16.000{,}000_{10}$, all filter points are scaled again by

$$16 \times 10^6/A.$$

All channels (0-12) are placed in 160A punch tape format. For those channels not listed in JCH (punch card), the filter coefficients are set at zero. Each filter coefficient takes the format of:

Word 1					Word 2					Word 3	
12 bits	12 bits	12 bits	12	12	12	12	12	12	12	12	12
Channel index (BCD)		Filter coefficient index (BCD)			mem. sub space (always 1)	output channel index (from card)		Filter Coefficient (octal)			tape feed (177)

All of the filter coefficients for each channel are combined into one record, and placed on magnetic tape. There are 13 records on the output tape (2).

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: Multi-channel Filters to Paper Tape

SWAP Identification: M221 Punch MCFONPT

Category: Conversion

Programmer: C. W. Clowes

Date: 2 October 1967

B. PURPOSE

This is a 160-A program using 1 tape unit and tape punch. Reads save tape from program MCFONPT and punches same on 8 channel paper tape. Must use 1 inch, eight channel tape, with 7 punches.

C. USAGE

1. Operational Procedure: Load Bi-octal tape into blank 0. Turn on punch, (check tape supply), master clear and run. Program will read input tape (1) and punch onto paper tape. When finished, tape will re-wind and stop at P=0214, A=0066. Run is completed. To re-run, master clear, run.

3. Space required: Program uses 113 160A words.

7. Error stops: P = 0140 A = 0077. Unable to read channel record, set jumpt key 1 to try reading again, off, process with error.

8. Input and Output Tape Mountings: Unit 1. Input tape.

9. Input and Output Format: Unit 1 input, 13 records of filter coefficients. 1 record per channel.

10. Selective jump switches: (see 7, error stops)

11. Timing: About 3 minutes

13. Caution to User: Make sure 1" tape is in punch.

14. Equipment Configuration: 160 A computer with paper tape punch and CDC 162 magnetic tape controller.

D. METHOD

3 feet of leader (177_8) is placed on paper tape followed by 13 records, read from magnetic tape (1) and punched one at a time. Each record is separated on paper tape by 1 tape feed character. 3 feet of trailer is punched on the end of paper tape.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: MULTICOH

COOP Identification: G630 MULTICOH

Category: Time Series Analysis

Programmer: J. Jih

Date: August, 1967

B. PURPOSE

This program computes multiple coherence functions for seismic array data rapidly and efficiently. Given an original set of N subset data channels, the program will compute the N-1 multiple coherence functions:

$$\lambda_i(N-i/N,\ldots,N-i+1) \qquad i = 1\ldots N-1$$

The program will then reorder the N data channels any number of times, each time computing another N-1 multiple coherence function. The print-out includes a description of the notation used. Optional print-out includes all the auto and cross spectra. In addition a provision exists to plot the multiple coherence functions. They Cooley-Tukey method of spectral estimation is used to botain high speed.

C. USAGE

1. Operational procedure: This is a Fortran-63 main program with the following subroutines: SUBTAPE, DETRND, XMNG1, COOLER, SMOOTH, PRINTSP, NOTATION, RESCALAT, CPLOT, and SPLOT. In addition, the following utility subroutines are assumed to be on the system tape: SKIPREC, ERASE, DISC63, and COOL.

2. Parameters: This program is set up to do multiple runs. It reads cards until an EOF is encountered and then terminates.

a) ISM - The seismogram number of the desired data.

b) N - The number of data channels to be used from seismogram ISM. ($2 \leq N \leq 20$)

c) LX - The number of digital points to be used from each data channel. LX must be a power of two ($LX \leq 4096$). If $LX \geq 4096$, it will be truncated to 4096.

d) L - The number of points desired in the multiple coherence functions between DC and the folding frequency. L must be a power of two plus one, i.e., 17, 33, 65, 129 etc. L must also satisfy the following bounds.

$3 \leq L \leq 33$ for $15 < N \leq 20$

$3 \leq L \leq 65$ for $11 < N \leq 15$

$3 \leq L \leq 129$ for $7 < N \leq 11$

$3 \leq L \leq 257$ for $5 < N \leq 7$

$3 \leq L \leq 513$ for $2 \leq N \leq 5$.

If these conditions are not met, L will be truncated.

e) ISPT - The first digital point of the desired data. ($ISPT \geq 1$)

f) IDT - The detrend switch:

= 0 or blank to remove the mean

= 1 to remove the mean and linear trend

= -1 for no detrending

g) INDX - The number of times to change the order of the original data channels and recompute the coherence functions. In all, INDX*(N-1) multiple coherence functions will be computed because the original order will not be changed.

h) MP - Switch for printing the power spectra

= 0 or blank for no printout

≠ to print power spectra

i) IPLOT - Switch for plotting the multiple coherence functions

= 0 or blank for no plot

≠ 0 to plot coherences.

j) NCODE - The spacing between plotted points in hundredths of an inch. All plots are to a five inch range.

k) ICH(I) - The position of the Ith data channel on the input tape.

l) SF(I) - The demagnification factor of the Ith data channel. SF(I) is divided into every point of the Ith channel. If SF(I) is 0.0 or blank it is set to 1.0.

m) IC(I) - An array of channel positions giving a new order for the data channels and hence new combinations of multiple coherencies. The N numbers in this array must be the same as those in ICH but can be in any order.

3. Space required: 20190 locations.

4. Temporary storage: DISC

5. Alarms: Various error messages are printed out for errors in the input data and parameters.

6. Error returns: none

7. Error stops: There are no stops. The program always proceeds with the next job request.

8. Tape mountings: An input tape of SUBSET seismograms must be on logical unit 1. A scratch tape must be mounted on logical unit 2. If plots are requested, an output tape must be mounted on logical unit 3.

9. Formats: For each case to be run the card deck is as follows: The first card lists parameters (a) through (j) as FORMAT (10I8). The second card lists parameters (k) and (l) as FORMAT (5(I2,F14.2)). If INDX=0 no further cards are read for this case. If INDX≠0 the next INDX cards list parameter (m) as FORMAT (20I3). The deck for the next request immediately follows.

10. Selective jumps: none

11. Timing: A N=5, LX=1024, L=17, INDX=0, MP=1,IPLOT=1, case takes 4 minutes of CDC 1604B time.

12. Accuracy: Single precision

13. Cautions to user: none

14. Equipment configuration: Standard COOP

15. References:

a) Bendat, and Piersol, Measurement and Analysis of Random Data, John Wiley & Sons, New York, 1966.

b) Frazer, Duncan, and Collar, Elementary Matrices, Cambridge University Press, Cambridge, 1963, pp.112-118.

c) Jih, write-up of subroutine XMNG, SDL, 1966.

D. METHOD

The multiple coherences of channel 1 with channels 2 and 3 removed is computed from the augmented spectral matrix S':

$$S' = \left(\begin{array}{c|cc} S_{11} & S_{12} & S_{13} \\ \hline S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{array}\right) = \left(\begin{array}{c|c} S_{11} & G^{+} \\ \hline G & S \end{array}\right)$$

where S is the spectral matrix of the channels to be removed and G is the vector of cross-spectra between them and the desired channel. The formula is:

$$\lambda^2(1/2.3) = 1 - \frac{\det S'}{S_{11} \det S}$$

The ratio of the determinants is calculated directly from the escalator method of matrix inversion. It is easily seen that all of the multiple coherences:

$$\lambda_i(N-i/N,\ldots,N-i+1) \qquad i = 1 \ldots N-1$$

can be calculated by the inversion of S' by saving the subratios of determinants in the escalator process.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: PARTLCOH

COOP Identification: G631 PARTLCOH

Category: Time Series Analysis

Programmer: J. Jih

Date: August, 1967

B. PURPOSE

This program computs partial coherence functions for taped data. The program also computes the amplitude and phase of the associated transfer function. The output includes printouts of these functions as well as plots of the coherence functions. The Cooley-Tukey method of spectral estimation is used to obtain high speed.

C. USAGE

1. Operational procedure: This is a Fortran-63 main program with the following subroutines: SUBTAPE, DETRND, XMNG2, COOLER, SMOOTH, BPLOT, PSP, RESCALAT, and SPLOT. In addition the following utility subroutines are assumed to be on the system tape: SKIPREC, ERASE, DISC63, and COOL.

2. Parameters: This program is set up to do multiple runs. It reads cards until an EOF is encountered and then terminates.

a) ISM - The seismogram number of the desired data

b) N - The number of data channels to be used from seismogram, ISM. ($2 < N \leq 20$). Any channel used to specify a partial coherence function must be a member of this original set.

c) LX - The number of digital points to be used from each data channel. LX must be a power of two ($LX \leq 4096$). If $LX > 4096$, it will be truncated to 4096.

d) L - The number of points desired in the partial coherence functions between DC and the folding frequency. L must be a power of two plus one, i.e., 17,33, 65, 129, etc. L must also satisfy the following bounds.

$3 \leq L \leq 33$ for $15 < N \leq 20$

$3 \leq L \leq 65$ for $11 < N \leq 15$

$3 \leq L \leq 129$ for $7 < N \leq 11$

$3 \leq L \leq 257$ for $5 < N \leq 7$

$3 \leq L \leq 513$ for $2 < N \leq 5$.

If these conditions are not met, L will be truncated.

e) ISPT - The first digital point of the desired data. (ISPT $\geq$ 1).

f) IDT - The detrend switch.

= 0 or blank to remove the mean
= 1 to remove the mean and linear trend.
= -1 for no detrending

g) INDX - The number of partial coherence functions to compute. (INDX $\geq$ 1).

h) MP - Switch for printing the power spectra

= 0 or blank for no print-out
$\neq$ 0 to print power spectra.

i) IPLOT - Switch for plotting the partial coherence functions.
= 0 or blank for no plot
$\neq$ to plot coherences

j) NCODE - The spacing between plotted points in hundredths of an inch. All plots are to a five inch range.

k) ICH(I) - The position of the Ith data channel on the input tapes. (I - 1,2,...,N). This specifies the original set of channels.

l) SF(I) - The demagnificati factor for the Ith data channel. SF( ) is divided into every point of the Ith channel. If SF(I) is 0.0 or blank it is set to 1.0.

m) NCH - The number of data channels involved in this particular partial coherence function. NCH $\leq$ N.

n) IC(I) - An array giving the channel positions of the data channels that specify this particular partial coherence function. The first two numbers specify the two channels between which the coherence is to be calculated. The next NCH-2 numbers specify the channels to be prediction filtered out. The numbers in this array must be the same as those in the ICH array but can occur in any order, numb , or combination. (I=1,2,...,NCH).

3. Space required: 20190 locations.

4. Temporary storage: DISC

5. Alarms: Various error messages are printed out for errors in the input data and parameters.

6. Error returns: none

7. Error stops: There are no stops. The programs always proceeds with the next job request.

8. Tape mountings: An input tape of SUBSET seismograms must be on logical unit 1. A scratch tape must be mounted on logical unit 2. If plots are requested, an output tape must be mounted on logical unit 3.

9. Formats: For each case to be run the card deck is as follows:

The first card list a parameters (a) through (j) as FORMAT (10I8). The second card lists parameters (k) and (l) as FORMAT (5(I2, F14.3)). The next INDX cards list parameters, (m) and (n) as FORMAT (21I3). The deck for the next request immediately follows.

10. Selective jumps: none

11. Timing: A N=5, LX=1024, L=33, INDX=3, MP=0, IPLOT=1, NCH=5,4,3, case takes 4 minutes of CDC 1604B time.

12. Accuracy: Single precision

13. Cautions to user: none

14. Equipment configuration: Standard COOP

15. References:

a) Bendat, and Piersol, Measurement and Analysis of Random Data, John Wiley & Sons, New York, 1966.

b) Jih, write-up of subroutine XMNG, SDL, 1966.

D METHOD

See reference (a), Page 315,316.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: F-K Plotter

COOP Identification: G636 PLOTFK

Category: Time Series Analysis

Programmer: D. W. McCowan

Date: October 1967

B. PURPOSE

This program takes a spectral matrix read from a binary program HEFALUMP save tape and plots requested f-k spectra. It was primarily designed to plot f-k spectra for averaged spectral matrices computed by program SPECAVE but will work with any HEFALUMP save tape.

C. USAGE

1. Operational Procedure: This is a Fortran-63 main program with the following subroutines: FKMAT, CNTRU5, LOCATION, READITIN, and SETCONST. In addition, the following utility subroutines are assumed to be on the system tape: DISC63.

2. Parameters:

   a) NF - The number of frequencies at which f-k plots are desired. NF $\leq$ 12.

   b) VELR - The velocity range for all f-k plots.

   c) FREQ(I)- The Ith requested frequency.

3. Space Required: 32K locations

4. Temporary Storage: DISC

5. Alarms: Alarms for requested frequencies. LE. the DC frequency and .GE. the folding frequency are printed.

6. Error Returns: none

7. Error Stops: none

8. Tape Mountings: An input save tape generated by either program SPECAVE or program HEFALUMP must be on unit 1.

9. Input Format: Parameters (a) and (b) appear on the first card as FORMAT (I5, F10.2). Parameter (c) appears on the next card as FORMAT (12F6.2).

10. Selective Jumps: none

11. Timing: A NCH=13, L=65, NF=6 case takes 16 minutes of CDC 1604B time.

12. Accuracy: Single precision

13. Cautions to User: none

14. Equipment Configuration: Standard COOP with RELOCOM

15. References:

Write-ups for HEFALUMP and SPECAVE by D. W. McCowan and FKSPTRUM by J. Jih.

D. METHOD

See References

SEISMIC DATA LABORATORY

Alexandria,Virginia

Digital Computer Section

A. IDENTIFICATION

Title: PREDICT

COOP Identification: G628 PREDICT

Category: Time Series Analysis

Programmer: V. R. Bruffey

Date: April 28, 1967

B. PURPOSE

To compute a prediction of the straight sum of multi-channel arrays, ispan units ahead in time where ispan is the prediction span. The predicted sum and the actual sum are subtracted to yield a prediction error, and all are plotted to the same scale factor. Also, to compute and plot power-spectra of these traces.

C. USAGE

1. Operational procedure: The program is written in Fortran-63 and uses the following subroutines:

(a.) MAKESUB -this subroutine reads an input seismogram and produces another seismogram with the desired data. It uses the subroutine DETRND which removes the mean or mean and linear trend.

(b.) MCORT -computes a correlation matrix. It uses subroutine DOT which performs a vector product.

(c.) BLMKGC -computes a prediction filter by the Levinson-Robinson recursion method. It uses subroutines MAINE and MATMPY which perform matrix inversion and matrix multiplication, respectively.

(d.) PHILTRE -convolves a filter with data to obtain filtered data.

(e.) SPECKS - computes the power-spectra of an array. It uses the subroutines SMOOTH and COOLER for smoothing data and computing the Fourier transform.

(f.) XPLOT - writes a plot tape with a given scale factor.

2. Options: The program can be run three ways, a Standard run, an Option 1, and an Option 2. The list below shows the calculations performed by each method.

Standard Method	Option 1	Option 2
Computes correlation matrix	Reads correlation matrix from a save tape	Reads filter from save tape
Computes prediction filter	Computes prediction filter	Filters data
Filters data	Filters data	Plots results
Writes save tape	Writes save tape	Computes power-spectra
Plots results	Plots results	Plots power-spectra
Computes power-spectra	Computes power-spectra	
Plots power-spectra	Plots power-spectra	

Note that Options 1 and 2 assume an input save tape generated by an earlier run of the program, and that Option 2 does not generate a save tape. A description of the save tape is given under the section Input and output tape mountings.

3. Parameters:

a) ISEIS - the seismogram number of the data

b) NCH - the number of channels to be processed

c) NPTS - the number of data points in the sample

d) ISPT - the first point of the requested data sample for each channel on the input tape.

e) IDETREND - switch for detrending the data. IDT= -1 for no detrending, IDT = 0 to remove mean and IDT = 1 to remove and linear trend.

f) JUMP - the number of elements skipped for each lag in correlation used in computing the filter.

g) ISPAN - prediction span in points

h) LENGTH - the number of lags of correlation used in computing the filter. Length is the number of elements, for each channel, in the filter.

i) IOPTION - switch for selecting the option. IOPTION = 0 or blank means standard run, IOPTION = 1 or 2 means Option 1 or Option 2, respectively.

j) ICH - an array of length NCH which specifies the data channels indices. For example, if the input tape contains channels Z1, Z2, Z6, Z7, and Z9, respectively, and one wants to process Z1, Z6 and Z9, then ICH (1) = 1, ICH (2) = 3, and ICH (3) = 5.

k) SF - an array of length NCH which specifies the demagnification factor for each requested channel.

l) ISTART - first point in the actual sum, predicted sum, and error used in calculating the power-spectra.

m) N - an integer such that the number of points for computing power-spectra = 2^n. If N = 0, no power spectra are computed.

n) NSM - an integer specifying the number of times to smooth the power-spectra.

4. Space required: 24598 locations used

5. Temporary Storage requirements: none

6. Alarms: none

7. Printouts: The program prints the program name, card input parameters, the power-spectra, and the performance factor.

8. Error printouts and stops: If any of the following errors occur, the type of error is printed out, and the program is stopped.

   a. Seismogram not on the tape
   b. Too many channels from the seismogram
   c. Too many points requested from the seismogram
   d. Illegal channel requested from the seismogram

9. Input and output tape mountings:

   a) Standard run

   Input subset tape on logical unit 3. Scratch tapes on logical units 56,57,2, and 4. Logical unit 4 is the plot tape and logical unit 2 is the save tape. The save tape contains, in binary logical records, the following information:

Record 1: ISEIS, NCH, NPTS, ISPT, IDETREND, JUMP, ISPAN, LENGTH, ICH(1) to ICH(NCH), SF(1) to SF(NCH)

EOF

Record 2: No. of points in the correlation matrix (NCH^2* (LENGTH+ISPAN))

Record 3: Correlation matrix

EOF

Record 4: No. of points in the filter (NCH*LENGTH)

Record 5: Filter matrix

EOF

Record 6: NPTS - JUMP*(LENGTH-1+ISPAN)

Record 7: Sum of data channels (actual array sum)

EOF

Record 8: NPTS - JUMP*(LENGTH-1+ISPAN)

Record 9: Predicted array sum

EOF

Record 10: NPTS - JUMP*(LENGTH-1+ISPAN)

Record 11: Error (actual array sum minus predicted array sum

b) Option 1

Input subset tape on logical unit 3. Input tape on logical unit 1, (must be a save tape in the format as discussed above). Logical units 2 and 4, 56 and 57 are scratch tapes. Unit 2 contains the resulting save tape in format described above. Unit 4 is the plot tape.

c) Option 2

Input subset tape on logical unit 3. Input tape on logical unit 1 (must be save tape in the format, as discussed above). Scratch on tape unit 4, 56, and 57. Unit 4 is the plot tape.

10. Input and output card formats: The format for card 1 is FORMAT (9I5). The parameters are right adjusted integers and are in the following fields:

Columns	Parameters
1-5	ISEIS
6-10	NCH
11-15	NPTS
16-20	ISPT
21-25	IDETREND
26-30	JUMP
31-35	ISPAN
36-40	LENGTH
41-45	IOPTION

Card(s) 2 has format (16I5). The parameters are right adjusted integers and are in the following fields:

Columns	Parameters
1-5	ICH(1)
6-10	ICH(2)
.	.
.	.
.	.
76-80	ICH(16)

If NCH >16 a second card must be used with ICH(17) in columns (1-5), ICH(18) in columns (6-10), etc.

Card(s) 3 has format (8F10.5). The parameters are floating point, and the numbers should be punched in their respective fields with decimal point.

Columns	Parameters
1-10	SF(1)
11-20	SF(2)
.	.
.	.
.	.
71-80	SF(8)

Repeated cards are used in the same manner as Card 2 if NCH > 8.

Card 4 has format (3I5). The parameters are right adjusted integers and are in the following fields:

Columns	Parameters
1-5	ISTART
6-10	N
11-15	NSM

The order of card input is as follows:

Standard run:

- Card 1, Card 2, Card 3 — parameters describe data from which filter is computed
- Card 1, Card(s)2, Card(s)3 — parameters describe data to be filtered
- Card 4

Option 1:

- Card 1, Card(s)2, Card(s)3 — parameters describe data to be filtered
- Card 4

Option 2: Card 1 ⎫ parameters describe data to be filtered
Card(s)2 ⎪
Card(s)3 ⎭
Card 4

11. Selective jump and stop settings: none

12. Timing: For 10 channels of data with 2000 points in each channel.

Standard run: 30 minutes

Option 1: 10 minutes

Option 2: 5 minutes

13. Accuracy: Single precision

14. Caution to users:

NCH $\leq$ 16
NCH(of data for filter computation)=NCH(of data being filtered)
LENGTH $\leq$ 40
ISPAN $\leq$ 10
NPTS $\leq$ 4000
N $\leq$ 10

15. Equipment configuration:

Standard run: 7/9 COOP,XXXXX,I/BY 1/3/S/ 2/4/56/57/E/5=56,60,5000.

Option 1: 7/9 COOP,XXXXX,I/ 1/3/S/ 2/4/56/57/E/5=56,60,5000

Option 2: 7/9/ COOP,XXXXX,I/ 1/3/S/BY2/4/56/57/E/5=56,60,5000.

16. References:

(1) Teledyne Internal Memorandum from E. A. Flinn and J. Claerbout to R. Van Nostrand, dated 16 September 1965. Subject "Some topics in digital filtering theory and application".

(2) McCowan, D.W., Teledyne Technical Memorandum No. 8-66, dated 16 December 1966, Title: "Finite Fourier Transform Theory and Its Application to the Computation of Convolutions, Correlations, and Spectra".

D. METHOD

The steps below show the general method used for computation.

(1). Compute correlation matrix of correlation functions:

$$R(i,j,L) = \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=0}^{M-1} X_i(K)\, X_j(K+L)$$

where M is the number of points per channel, N is the number of channels, and L is the lag. See reference (1).

(2). Compute prediction filter using the Levinson-Robinson recursvion method.

(3). Filter data

(4). Plot direct sum of data channels (actual sum), and the predicted sum. Also plot error, where error = actual sum - predicted sum.

(5) Compute power-spectra of the three traces above. See reference (2).

(6) Plot power-spectra traces and a performance trace where performance = 1 - error spectra/actual spectra.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computing Section

A. IDENTIFICATION

Title: Spectral Matrix Averaging Program

COOP Identification: G635 SPECAVE

Category: Time Series Analysis

Programmer: D. W. McCowan

Date: October 1967

B. PURPOSE

This program computes and averages spectral matrices for multichannel seismic array data. The output of this program is a tape in the same format as the program HEFALUMP save tape. Using that tape as input to the HEFALUMP program allows the user to compute multichannel filters from an ensemble of noise spectra. This program is also designed to add to or update an ensemble spectral matrix on tape from a previous run.

C. USAGE

1. Operational procedure: This is a Fortran-63 main program with the following subroutines: MAKESUB, DETRND, COOLER, SMOOTH, and XMNG. In addition, the following utility subroutines are assumed to be on the system tape: ERASE, COOL, DISCG3, and SKIPREC.

2. Parameters: The user is referred to the write-up of program HEFALUMP for a clearer explanation of some of these parameters.

a) NCASES - The number of spectral matrices to compute and add to the ensemble in this run.

b) ISW - The run designation switch.
ISW=0 only the NCASES spectral matrices computed this time will be on the save tape.
ISW≠0 the NCASES spectral matrices computed this time will be added to the ensemble input on a save tape from a previous run mounted on unit 4 and written on the save tape.

c) ISEIS - The seismogram number of this sample of data.

d) NCH - The number of channels in this sample of data. This must be the same for each sample. NCH $\leq$ 13.

e) NPTS - The number of points in this sample of data. NPTS must be a power of two. NPTS $\leq$ 4096.

f) ISPT - The first point.

g) IDT - The detrend switch for this sample.
IDT = -1 for no detrending.
IDT = 0 to remove the mean.
IDT = 1 to remove the mean and linear trend.

h) L - The number of points desired in the spectral estimates. L must be a power of two plus 1 and must be the same for each sample. L $\leq$ 129.

i) IPAUSE - A pause switch.
IPAUSE = 0 has no effect.
IPAUSE = Ø pauses with the index number of the sample being computed in the A register to allow a new input subset tape to be mounted.

j) ICH(I) - The channel index of the Ith data channel of seismogram ISEIS. ICH(I) = 4 indicates the Ith data channel is the fourth on the input tape, etc.

k) X(I) - The X coordinate of the Ith data channel. This is optional input.

l) Y(I) - The Y coordinate of the Ith data channel. This is optional input.

m) SF(I) - The demagnification factor for the Ith data channel. This number is divided into every point of the Ith data channel. If it is 0.0 it is set to 1.0.

3. Space required: 32K locations

4. Temporary storage: DISC

5. Alarms: Various alarms for illegal data are printed out.

6. Error returns: none

7. Error stops: A stop occurs after each alarm.

8. Tape Mountings: Tape unit 1 is the input subset tape which can be changed during execution by using the pause feature. Tape unit 2 is the output save tape containing the sum of all computed spectra and any input from a previous run. Tape 3 is a scratch tape. Tape 4 is an input save tape from a previous run of this program, if so desired. If not, it should be neglected with the BY feature of the monitor.

9. Input and output formats: Input cards:

   Parameters (a) and (b) appear on the first card as FORMAT (2I10). There follows NCASES data decks of the form: card 1 containing parameters (c) through (i) as FORMAT (I10,6I5), and the next cards containing parameters (j) through (m) as FORMAT (3(I3, 2F8.2, F6.2)).

   Save tape: The save tape consists of the two logical records of binary data. The first record is a 127 word binary label written as follows:

LAB(1) = ISEIS	LAB(100) = IDT
LAB(2) = NCH	LAB(101) = L
LAB(3) = NPTS	LAB(58--58+NCH-1) = X
LAB(99) = NCASES	LAB(79--79+NCH-1) = Y

   The values of NCH, NPTS, IDT, L, X and Y that appear in the label are those of the last data sample. NCASES is always updated in this program and thus is an accurate number of the separate spectral matrices in the ensemble. ISEIS, in true fashion, is the average of the values read in for the samples.

   The second record is a 21801 word array with the averaged ensemble spectral matrix stored close packed and written as follows:

$S_{ij}(w)$ = S(k,j,w), ((S(i,j,w), i = 1, NCH), j=1, NCH), w=1,L)

10. Selective jumps: none

11. Timing: See write-up of subroutine XMNG.

12. Accuracy: Single precision

13. Cautions to user: none

14. Equipment configuration: Standard COOP with RELOCOM.

15. References:

Write-ups of program HEFALUMP and subroutine XMNG by D. W. McCowan and J. Jih respectively.

D. METHOD

See references.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: Spatial interpolation

COOP Identification: G625 TWX

Category: Time Series Analysis

Programmer: E. A. Flinn

Date: 13 February 1967

B. PURPOSE

To compute a least-mean-square-error filter which interpolates one channel of an array from certain other channels in the array, apply the filter to construct an interpolated estimate, construct the error time function, and display the power spectrum of the error.

C. USAGE

1. Operational procedure: This is a main program written in Fortran-63. Relocom and Executer are both required.

2. Parameters: The following control parameters are input from cards (see C.9 below):

a) NSEIS - Seismogram number containing data to be filtered. The data is read in from a subset tape, but the specified seismogram does not have to be the first seismogram on the tape. An error stop occurs if the seismogram is not on the tape at all.

b) NCH - Number of channels to be re-subset from the input subset tape.

c) I1 - Start point for re-subset.

d) I2 - Number of points to re-subset. Error stop occurs if I1+I2 is greater than the third word of the subset seismogram label.

e) CHN - Hollerith designator for the channel to be interpolated. Error stop occurs if label of input subset tape does not contain this designator.

f) NSM - Number of times to decimate the filtered data by two, in constructing the spectra. Only the first N points of the filtered trace are used in forming the spectra, where N is the largest power of 2 less than the number of data points. For example, 1035 input points are reduced to 1016 by filtering with a 20-point filter. The program takes the first 512 data points in forming the spectra. Suppose NSM = 4: then the 512 points are reduced to 512/4 = 32 spectral points which are plotted.

g) LAGS - Number of elements in the filter and number of lags in the correlation matrix. Maximum is 50.

h) IPLOTR - Plot control switch for the correlation matrix; input zero, correlation matrix is plotted; input non-zero, omit plot.

i) ICHN - Channel number to interpolate, counted after re-subsetting. See definition of ISUB below. For example, suppose there are 5 channels in the input tape; these are taken to be numbered 1, 2, 3, 4, 5. If we wish to interpolate channel 3 from channels 1 and 4, we make NCH = 3 (see above), ISUB(1, 2, 3) = (1, 3, 4) (see below), and put ICHN = 2, since the channel to be interpolated is the second channel on the re-subset tape.

j) ICOR - Switch for computing correlation matrix and filter or reading them in off tape. ICOR = 0 causes correlation matrix and filter to be computed and saved on a binary output tape on unit 9. (see C.9 below).

ICOR = 1 makes the program read in the correlation matrix and filter coefficients from binary tape. An error stop occurs if NCH is not equal to the second word of the label of the tape on 9, and if LAGS is not equal to the third word of the label of the tape on 9.

The filter is recomputed if CHN is not equal to the 37th word of the label of the tape on 9.

In any case, the tape on 9 is re-wound and rewritten (see C.9 below)

k) IPLOTX - This allows the plots to be less than full-length,ie, I2-I1-LAGS points. Non-zero, only IPLOTX points are plotted. An error stop occurs if IPLOTX exceeds I2-I1-LAGS.

l) ISUB - An integer array of channel numbers to re-subset. These must be arranged in increasing numerical order. If all channels are to be re-subset, ISUB may be left blank.

m) SF - An array of channel magnifications, arranged in the same order as ISUB. Each re-subset channel is divided by the corresponding magnification. Any element of SF left blank is set to 1.0 by the program.

3. Space required: 32K using Relocom and Executer.

4. Temporary locations: none

5. Alarms and special printouts: none

6. Error returns: not applicable.

7. Error stops: An error message is printed and the program stops under the following circumstances.

a. Requested seismogram not on input subset tape.

b. Number of channels requested greater than number of channels in requested seismogram or greater than 16.

c. Number of points requested greater than number of points in requested seismogram.

d. Label of requested seismogram does not contain channel with designator CHN (see C.2 above).

e. Number of lags input exceeds 50.

f. When correlation matrix is read in from input tape, NCH different from second word of label or LAGS different from third word of label.

g. ISUB not in increasing numerical order.

8. Tape mountings:

Input tapes -

1 Input subset tape.
7 Card input.
9 Correlation matrix and filter (optional).

Output tapes -

2 Plot.
6 Printer.
9 Correlation matrix and filter.

Scratch tapes: 3,4,5

The COOP card arrangement for using on-line card reader and printer is: I/1/0/2/S/3/4/5/9/E/7=50/6=51/8=54.

9. Input and output formats: Input cards -

Card 1: Format (4I5, 2X, A3, 6I5)

Columns	Data	Explanation
1-5	NSEIS	Seismogram desired.
6-10	NCH	Number of channels to be re-subset. (maximum is 16).
11-15	I1	Starting point for re-subset.
16-20	I2	Number of points to be re-subset.
23-25	CHN	Hollerith designator for channel to be interpolated.
26-30	NSM	Number of times to decimate spectra by 2 before plotting.
31-35	LAGS	Number of elements in filter (maximum is 50).
36-40	IPLOTR	= 0 plot correlation matrix; ≠ 0 omit plot.
41-45	ICHN	Order number of CHN on re-subset tape.
46-50	ICOR	=0 compute correlation matrix and filter, and write on tape 9. ≠ 0, read in correlation matrix and filter from tape 9 (filter is recomputed if CHN differs from word 37 of label of tape 9).
51-55	IPLOTX	= 0 plot channel CHN, interpolated estimate of CHN, and error, all full-length;

negative, omit above plots.
positive, plot only IPLOTX points.

Card 2: Format (20I3)

This card contains ISUB, an integer array of channel numbers to be re-subset. An error stop occurs if these are not in increasing numerical order. For example, to re-subset channels 1, 3, and 4, punch 1 in column 3, 3 in column 6, and 4 in column 9.

Card 3 and 4: Format (12F5.0)

These cards contain SF, the array of channel magnifications for the re-subset tape. The magnifications must correspond to the elements of ISUB. In the above example, columns 1-15 of card 3 would contain the magnifications for channels 1, 3, and 4; card 4 would be blank. Any magnifications left blank will be set to 1.0 by the program. Thus if no demagnification is required, cards 3 and 4 may both be left blank.

Input Tapes -

1: A data tape in subset format, containing seismogram number NSEIS.
9: See output formats below.

Scratch tape-

5: A re-subset version of the input tape 1, containing only NCH channels as specified by ISUB, i.e., the label is the same as the label on tape 1, with the following exceptions: word 2 = NCH; word 3 = I2-I1+1; the first NCH words of the channel designator group (beginning at word 8) are the designators of the NCH channels as specified in ISUB. This tape is later overwritten by the program.

Output Tapes -

2. Plot tape:

a. Correlation matrix (if IPLOTR = 0), displayed in standard matrix form: half the channel autocorrelations down the diagonal, the right half of the crosscorrelations above the diagonal, and the (reversed) left halves of the cross-correlations below the diagonal.
b. Input channel CHN.
c. Interpolated estimate of CHN.
d. Error - (b) minus (c).

(b,c,d are all to the same scale factor, with range ½ inch. The maximum value in CHN is written in BCD on the plot)

e. Error, with its own scale factor.
(b,c,d,e are full-length, i.e., contain I2-I1-LAGS points, unless IPLOTX are non-zero, in which case the plots contain IPLOTX points)

f. Spectrum of CHN; maximum is identified.

g. Spectrum of interpolated estimate of CHN; maximum is identified.

h. Spectrum of error (trace d above); maximum is identified.
(f,g,h are all to the same scale factor, with range 1½ inches, plotted linearly. The left end of the plot corresponds to zero frequency, the right end to the folding frequency - half the sampling given in the label. The number of points in plots, f. g. h. i is K = N/NSM, where N is the largest power of 2 less than I2-I1-LAGS.)

i. Performance factor, defined as 1.0 minus the ratio of interpolated spectrum to input spectrum, i.e., 1.0 - (g)/(f).

9: Correlation matrix and interpolation filter:

Record 1: Label, identical to label on scratch tape 5 above, except that word 37 = CHN.

Record 2: Correlation matrix, written with the statement WRITE (9) ((R(I,J,K), I=1, NCH),J=1,NCH), K=1, LAGS).

Record 3: Interpolation filter, written with the statement WRITE (9) ((G(I,J), I=1,NCH), J=1,LAGS).

Printer -

Various headings, the first hundred words of the input channel CHN, the interpolated estimate of CHN, and the error; the spectra of CHN, the interpolated channel, and the error, and the performance factor are printed.

10. Jump settings: none

11. Time Required: depends on the number of channels and the length of the filter. Time is dominated first by computation of the correlation matrix and second by computation of the filter. Typical times - for 50 lags and 10 channels, 45 minutes to compute the correlation matrix, 12 minutes to compute the filter, and 3 minutes for everything else. 5 channels and 20 lags requires 15 minutes.

12. Accuracy: single precision

13. Cautions to user: Refer to error messages above

14. Equipment configuration: standard COOP

15. References:

SDL Report No. 168 "Finite Fourier Transform Theory and its Application to the Computation of Convolutions, Correlations, and Spectra", by D. W. McCowan, 15 December 1966.

SEISMIC DATA LABORATORY

Alexandria, Virginia

Digital Computer Section

A. IDENTIFICATION

Title: VFKSPTRUM

COOP Identification: G629 VFKSPTRUM

Category: Time Series Analysis

Programmer: J. Jih

Date: 2 June 1967

B. PURPOSE

To compute and display the frequency-wave number power spectra of seismic noise along with a response function for the corresponding vertical array.

C. USAGE

1. Operational procedure: This is a Fortran-63 main program with the following subroutines: FKMATRIX, SMOOTH, COOLER, MAKESUB, DETREND, and CNTUR6. In addition, the following utility subroutines are assumed to be on the system tape: SKIPREC, ERASE, DISC63, and COOL.

2. Parameters: This program processes job requests in sequence, reading in the required data cards each time. Each job requires the following data cards:

A. The first card lists the following parameters as FORMAT (6I10, 2F8.5, 2I2):

a. ISM - the seismogram number of the desired data.

b. N - the number of data channels to be used. $1 \leq N \leq 24$.

c. LX - the number of digital points to be used from each data channel. LX must be a power of two. ($32 \leq LX \leq 4096$). If LX > 4096, it will be truncated to 4096. If LX < 32, it will be set to 32.

d. ISPT - the first point of the desired data. ($1 \leq ISPT$).

e. IDT - the detrend switch.
= 0 or blank to remove only the mean
= 1 to remove the mean and linear trend
= -1 for no detrending.

f. NK - the number of K, vertical wave number, values to compute. ($1 \leq NK \leq 99$).

g. SK - the lowest K value to compute

h. DK - the increment between successive K values.

i. IDEC - a decimation parameter. AN F-K contour between DC and the (folding frequency) *2**(1-IDEC) will be computed and displayed. If IDEC < 1, it will be set to 1. 2**(IDEC+4) $\leq$ LX.

j. IRESP - a response switch.
= 0 or blank for no array response
≠ 0 for a plot of the array response.

B. The next cards list the following parameters as FORMAT (4(I2,F9.3, F9.3)):

a. ICH(I) - the position of the Ith desired data channel on the input seismogram. ($1 \leq I \leq N$).

b. Y(I) - the depth of the Ith desired data channel. ($1 \leq I \leq N$):

c. F(I) - scale factor for the Ith channel, which is divided into the data, ($1 \leq I \leq N$). It will be set to 1, if it is zero or blank.

3. Space required: 20480

4. Temporary space: DISC

5. Alarms: See write-up of "MAKESUB".

6. Error returns: none

7. Error stops: There are two error stops:

a. The control data cards are not enough.

b. N, NK or DK is illegally requested.

8. Tape mountings: An input tape of subset seismograms must be on logical Unit 1. A scratch tape is needed and must be on logical Unit 2.

9. Selective jumps: none

10. Timing: Example N = 5, LX = 4096, NK = 21, IDEC = 4, IRESP = 1, case takes 7 minutes of CDC 1604B time.

11. Accuracy: Single precision

12. Caution to user: none

13. Equipment configuration: Standard COOP

14. References: See write-up of "FKSPTRUM".

D. METHOD

The frequency-wave number power spectra are computed from the spectral matrix elements by the following relation:

$$P(f,k) = \sum_i \sum_j Sij(f)_\ell \, e^{-2\pi i f(y_i - y_j)}$$

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

TELEDYNE, INC.
ALEXANDRIA, VIRGINIA

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b GROUP

3 REPORT TITLE

DIGITAL COMPUTER PROGRAMS FOR THE DESIGN AND EVALUATION OF MULTICHANNEL FILTERS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific

5. AUTHOR(S) (Last name, first name, initial)

McCowan, D.W.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
26 January 1968	72	

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
F 33657-67-C-1313	
b. PROJECT NO. VELA T/6702	210
c. ARPA Order 624	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. ARPA Program Code No. 5810	

10. AVAILABILITY/LIMITATION NOTICES

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Chief, AFTAC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	ADVANCED RESEARCH PROJECTS AGENCY NUCLEAR TEST DETECTION OFFICE WASHINGTON, D. C.

13 ABSTRACT

This report lists program write-ups for the multichannel filter program set written under the multichannel filter project here at the SDL. All of these programs were verified using these write-ups which are now as free from errors as possible. This set of programs should provide a reasonably complete capability to analyze signals and noise, design multichannel filters to enhance signals and suppress noise, evaluate the performance of these filters and prepare the punched paper tape which inputs the multichannel filters into the Texas Instruments Digital converter.

14 KEY WORDS

Digital Processing of Seismic Data
Multichannel Filters

Unclassified

Security Classification